



Early Journal Content on JSTOR, Free to Anyone in the World

This article is one of nearly 500,000 scholarly works digitized and made freely available to everyone in the world by JSTOR.

Known as the Early Journal Content, this set of works include research articles, news, letters, and other writings published in more than 200 of the oldest leading academic journals. The works date from the mid-seventeenth to the early twentieth centuries.

We encourage people to read and share the Early Journal Content openly and to tell others that this resource exists. People may post this content online or redistribute in any way for non-commercial purposes.

Read more about Early Journal Content at <http://about.jstor.org/participate-jstor/individuals/early-journal-content>.

JSTOR is a digital library of academic journals, books, and primary source objects. JSTOR helps people discover, use, and build upon a wide range of content through a powerful research and teaching platform, and preserves this content for future generations. JSTOR is part of ITHAKA, a not-for-profit organization that also includes Ithaka S+R and Portico. For more information about JSTOR, please contact support@jstor.org.

THE MEASURE OF EXCELLENCE IN SCIENTIFIC ACTIVITY

By Professor R. D. CARMICHAEL

UNIVERSITY OF ILLINOIS

THE fundamental scientific activity is that which is expended in the search for truth, in discovering and establishing what can be made sure by experiments or by undisputed logical processes convincing to all who understand their nature. But truth has value only as it exists in the minds of men and women who procure from it practical or ideal benefits for themselves or others. Consequently scientific workers must see to it that a suitable portion of the body of truth is made widely known and is preserved for future generations. This calls for the work of the teacher and for the publication of the results of research. It also demands a certain measure of educational propaganda, at least in a country where scholarly traditions are just being developed, in order to create and maintain the proper interest in scientific truth and an appreciation of its values. Let us consider first this essential secondary part of scientific activity, the part which has to do with the dissemination of results once attained.

In a country in which research is as new as it is in ours and in which no controlling spirit of tradition is in existence for the maintenance of ideals, there is danger of thinking too lightly of breaking up the research work of an active man by assigning to him editorial duties in connection with periodicals both for the record of scientific achievement and for the work of educational propaganda. Committees of scientific organizations charged with the duty of procuring a man or a group of men to do such editorial labor are inclined to place an undue emphasis upon the work for which they are temporarily responsible and to seek appointees for it without a sufficiently keen realization of the needs of science as a whole. Unfortunately it sometimes requires actual experience with editorial work for a research man to realize how fundamentally it will break up the continuity of his thinking; and through this failure to see the true situation beforehand he may enter upon a labor in which he will be compelled to look upon himself as one of the principal offenders in the development of a spirit of thinking lightly of breaking up research work, although there is nothing in which he believes more ardently than in the value of ascertaining new truth.

The aptitude required for research and that for editorial labors are distinct in their character and there is no reason to believe that the possession of the one implies that of the other. In fact it is rare to find the two prominently present in the same individual. There are two types of things to be accomplished and two types of men from whom are to come the persons to accomplish them. In advancing a matter of secondary importance, essential though it is, we should be careful not to hinder the more vital work of research. Neither of these two things can be separated from the general cause of science. Moreover, we must keep in mind also the welfare of the individual who is asked by his colleagues to undertake any particular definite piece of work. To be sure, the cause of science is of sufficient importance to justify a considerable sacrifice on the part of one person in order that the general cause may prosper to the best advantage, unless that person is one of the most vital thinkers among his colleagues. Such a one should be left entirely undisturbed. In all cases we are in duty bound to find for each particular labor to be assigned a man who can do it without departing too widely from the things in which he is naturally interested and to which he is temperamentally adapted.

It is essential to our best welfare not only that a correct judgment of values shall be maintained among practised scientific workers but also that the younger men as they come along shall be led to a proper emphasis of values. There is a tendency in some quarters to magnify the importance of editorial work and to esteem it as the basis of as high preferment among one's colleagues as almost any service that could be rendered. There is danger that this error shall be particularly insidious in its influence upon the younger scientists; and it needs therefore to be brought into the light of day where it can not live. It must not be true, and we must not allow the feeling to develop, that it is likely to be of personal advantage to our scientists for them to give up a significant portion of their creative labors in order to perform editorial or any other duties of a secondary sort. Creative work alone produces the more fundamental values. It would be injurious to the cause of science in our country if anything should be done to create the feeling that it is a light matter to lay down research work from any considerations whatever having to do with less vital matters. Let us make sure that there is nowhere in our scientific atmosphere a source of infection breeding such dangers to our young scientists.

In certain subjects, as for instance that of pure mathematics, there is at present a great lack of scholarly and sufficiently complete expositions in English of the matters of central impor-

tance. The number of mediocre or very elementary books is great, in fact so great that it seems to be desirable to lessen the future output by means of a definite public opinion disapproving the appearance of books not having a sound scientific reason for their existence. But it is a distinct service of a high order, above that of editorial labors, to produce scholarly expositions from a sufficiently advanced point of view.

It is therefore important that we shall encourage the production of such books. Two essentials will have to be supplied: it requires well-trained scientists of keen insight to prepare the manuscripts; then there must be publishers willing to invest capital in the enterprise in order to put the book before the public. The latter need will take care of itself and writers will be encouraged to supply the former if such books begin to have a sufficient number not only of readers but also of purchasers. We need to develop the disposition to distribute more widely in public libraries the scientific books of higher grade and the inclination on the part of scientists to enlarge their private libraries. The existence of a large number of discriminating buyers would certainly stimulate the production of the books desired. To buy as many important books as you can use with profit and not as few as you can get along with is to do good to yourself and also to render service to the cause of science.

Nearly all scientists in America have superimposed upon their other activity that of the teacher. Unfortunately the time and energy of not a few men of originality and insight are too largely consumed in elementary instruction which might well be given by persons of less training and sometimes with advantage to the learner. Thus we might release the men of other temperament for that different work which can be performed by only a relatively small number of people. But it is desirable, from the point of view both of the learner and of the scientist himself, that lectures on advanced topics shall be given only by men actively and vitally engaged in research. To the former comes the value of contact with insight, power, and enthusiasm; to the latter, the inspiration of seeking a living exposition by means of which a new mind shall acquire a previously unrealized power.

In order that teaching shall proceed to the best advantage there must be some organization by means of which the various parts of the work shall fit together; and this calls for administrative officers. Unfortunately the work of these in American institutions is magnified beyond its deserts, especially in some of the newer universities which only lately have laid aside the garments of the college. In such institutions many hold-overs

from the old régime are to be found, both as heads of departments and as other men of the more advanced rank in the university. Some of these are such that no word of criticism is to be spoken against them; and some are at the other extreme without the grace to remove themselves from an impossible position. These evils do their greatest harm perhaps in operating to make it difficult for the youths to form correct judgments of value.

As science develops it is of increasing importance that we shall prepare histories of it in the form likely to be made useful in the several ways in which they may be of value. There are three distinct primary needs which may be supplied by histories of science, namely: To enrich the general culture and intellectual life of educated people; to enable a scientific worker to quickly orient himself in a chapter of a science so as to proceed most readily to a detailed mastery of its literature; to enable a scientific worker to ascertain with completeness what has already been attained in a given subject.

To serve any one of the three purposes indicated requires a very different treatment from that needed in the case of the others. The literature at present in existence is totally inadequate in each of the classes; and it seems now likely to remain so for some time. For a few well-confined subdivisions of the several sciences, and for such alone, have we sufficiently comprehensive histories for the workers in particular sciences; and nowhere is there yet made suitable provision of historical material in science for the needs of general culture. In this portion of the history of thought, therefore, is to be found a great opportunity for service to the cause of science and of human progress. The work to be done calls for full training and for insight of a high order.

But the primary and most fundamental requisite for general scientific progress is discovery and verification of new truth. After the worker has been found who may enter upon this labor the next essential is his acquisition of knowledge in the domain in which his energies are to be expended. He must be familiar with a certain measure of the results obtained by his predecessors. The only approach from our side to the boundary of knowledge is along a path which leads through fields of truth already explored; and he who is unable or unwilling to travel such a path will waste in fruitless endeavor whatever energy he expends in trying to penetrate into the unknown.

But the path along which he approaches the boundary of knowledge may vary greatly with the individual thinker, being affected both by his temperamental aptitudes and by his total

measure of power. One will see by an almost unerring intuition the significance and bearing of a given restricted body of doctrine as soon as he is in possession of the truth which constitutes it. Another must know in detail the various related doctrines before he can come to a realization of the import of the first one. It is clear that two aptitudes as widely separated as these demand distinctly different means for the acquirement of truth and for the realization of further progress.

Perhaps the matter may be clarified by a figure. The man of less native force will probably find it necessary to approach the boundary of knowledge along a spiral path which starts from some place in the interior and winds round and round repeatedly, always coming a little closer to the boundary and approaching it asymptotically. This method requires the maximum time and energy for reaching the neighborhood of unexplored territory. Moreover, the line of progress is along a path not far removed from a parallel to the boundary. Consequently the component of momentum in a direction perpendicular to the boundary is small, at least in those places where the boundary is more regular. One who proceeds along a spiral path of learning will therefore have the greatest facility for penetrating the unknown if he finds a narrow cape from the continent of ignorance projecting far into the ocean of acquired truth; and here he will carry on explorations of value, but will hardly be able to open a new region of large extent.

It is obvious that discoveries originating in this way tend to round out and make regular the total body of known existent truth. But it is unlikely that they shall bring within our grasp any body of truth of essential novelty. It would seem therefore that the spiral method of approach to the boundary of knowledge is best suited to those prospective researchers who are of mediocre ability; and that others, having first acquired a suitable general fund of knowledge, should then proceed more directly toward territory as yet unexplored.

This calls for what may be termed the radial method of approach to the boundary of knowledge, that in which one proceeds along a path more or less nearly normal to that boundary. We suppose that one who is to go in this direction shall have first acquired a suitable preliminary acquaintance with the more fundamental matters in his particular science as a whole. Moreover he must be one of those of greater native force or he will be lost in proceeding directly far into unfamiliar territory. But if he has the proper central fund of information and the requisite native force of intellect he can proceed along such a radial path with increasing momentum. Now, practically the

whole of this momentum is in a line perpendicular to the boundary and consequently will serve as a means of breaking through and perhaps of penetrating far into previously unexplored territory.

It is obvious that discoveries arising in this way have the greatest likelihood of opening up new regions of vast extent; and they may even issue in the introduction of fundamentally new ideas. Perhaps our greatest progress is realized from an assault of this sort upon the unknown, one along a fortunate direction chosen by dumb intuition or by a prevision of the character of the advance to be anticipated.

The advantages of radial approach are not altogether denied to those who are restricted by inherent limitations to the spiral method of acquiring known truth. After they have come into possession of a certain general body of doctrine they may select out one line of development in it and proceed through this in a radial direction to the boundary of knowledge and thus have the advantage of a realization of the full momentum of their progress. But they will lack the zest and enthusiasm which characterizes a first view of beautiful truth, and this will usually dim their insight and preclude the greatest conquests. Nevertheless, it must be admitted that some of our very important discoveries are made in this way, particularly among those which are intimately associated with bodies of doctrine for a long time in a state of high development.

In estimating the measure of excellence in scientific activity one can not leave out any fundamental element in the culture of mankind. Our development is as a whole and not in fragments. To be sure, the growth at any one moment may be in spots; but there is a constant interaction among the various parts and a consistent evolution of the whole. One portion of the body of truth can not develop far while all other portions are in a resting state. Each needs the stimulation which comes to it from discoveries beyond its own boundaries and the encouragement consequent on seeing the fruit which itself yields in other domains. Let us therefore consider the values arising from the interaction of science with other general divisions of thought.

Among certain scientists there is a tendency to underestimate the value of philosophical thought owing to the influence of a subtle error in logic arising from reaching a conclusion without formulating wholly in consciousness the argument by means of which the conclusion is attained. Among these scientists it is the custom to reckon as a part of science any well-established results which have met what seem to be the appro-

priate tests of truth, regardless of how these results are first obtained. Therefore, whenever any range of thought has reached a stage of development at which it is able to exhibit definite conquests it becomes, at least in the region of these conquests, a part of the general body of science.

Now in philosophy there has always been much that is speculative. But if philosophy should get its feet on solid earth and attain a conquest definitely achieved these same scientists would take the achievement out of the realm of philosophy—and perhaps rightly so—and annex it to the domain of science. Such a procedure seems rather hard on philosophy; but it might be passed over in silence if it were not followed by an injustice which it is made to support.

These same scientists when they have taken out of philosophy every definite conquest and transferred it to the realm of science, then intimate that philosophy is without essential value; and to drive this intimation home with compelling power they demand with gusto to know what is the single definite achievement belonging to the domain of philosophy, whereas, according to their accepted principles, any definite conquests made by philosophy would pass from philosophy into science in the act of becoming definite. Thus they draw the line of demarcation between science and philosophy so that all definite conquests lie in the domain of the former and so that only speculative or unestablished opinions belong to the latter, and then they decry philosophy as useless because it contains no body of well-established truth as part of its permanent possession. This procedure is unscientific and unjust.

In order that philosophy, even so restricted, may be denied a place of importance in the development of scientific truth, one must show not only that it has made no permanent conquests but also that it has failed to assist materially in preparing the way for the advancement of science. This latter can hardly be maintained even by the most narrow devotees of science; for it is notorious that the atomic theory and the theory of evolution, central as they are in all modern natural science, were at home in philosophy for generations before they took a form in which they might be used in the domain of more exact truth. Their presence for a long time to the thought of mankind was one of the essential prerequisites to their use in connection with knowledge obtained by experiment and observation. Thus two of the most fundamental conceptions in modern science, one having to do with non-living and the other with living objects, have come into their own with the assistance of speculative thought.

From many points of view we are forced to a consideration

of the question as to where philosophy ends and science begins or to the conclusion that there is no dividing line and that the two names represent different aspects of the same thing. Now it seems clear that there is a difference in character between the extremest speculations of philosophy and those parts of science which are so far advanced as to furnish means of precise and accurate prediction. And if there is this essential difference in the more widely separated parts of the two bodies of thought it appears that we must grant them to be different even though at some places they may approach so closely together as to have a common boundary.

Assuming, then, that there is a valid distinction, let us raise the question in some such concrete form as the following. The early statements of the atomic theory of matter (among the Greeks) are clearly speculative in the highest degree and as such belong to philosophy; in our day the atomic theory is characteristically scientific, having the most intimate connection with a large body of experimental results. In the development of this theory where does philosophy end and science begin? The question has a two-fold aspect. Historically, when did the exclusively speculative character of the doctrine take on a scientific form? and to what extent had the theory advanced historically when one should first begin to call it scientific? Logically, what was the state of affairs when one may properly begin to speak of the theory as scientific?

To follow out these questions with care would probably throw considerable light on the fundamental problem as to the relation between science and philosophy. One ought if possible to establish certain definite criteria or sets of criteria of such sort as to distinguish with clarity between that which is scientific and that which is philosophical, except possibly for a narrow ambiguous band lying along the common boundary. Thus, if a theory has reached a stage where it enables us to predict with accuracy certain definite phenomena, there seems to be no doubt that it should be classed as scientific. If this quality is absent should we say that the theory is still in the less advanced stage of philosophy? Or, should we make our test for scientific character less stringent and say that the theory, whether established or not, belongs to science if it is so formulated as to enable us to conceive definite means of subjecting it to experimental test? These are questions on which as yet there seems to be no general agreement.

In science itself there are two bodies of doctrine so distinct in some of their leading characteristics as to be often opposed one to another, namely, natural science and mathematics. In

fact, one often has in mind the former when he speaks in a general way of science, using no qualifying word. In such wise have we used the term in the foregoing study of the relation of science and philosophy. Let us now still more definitely make the separation and proceed to a consideration of the relations between natural science and mathematics.

Some workers seem to resent the interference of mathematics with their comfort in the conclusions of descriptive science and its demands that observation shall be reduced to measurable elements and the laws of nature be expressed in mathematical formulas; other thinkers believe that natural science is real science only in so far as it is mathematical, that it is only through mathematics that true science can be understood, and that without mathematics no science can develop to maturity. One delights in observation and the record of facts, believing that he has understood a class of phenomena when he has given a general description of their relations, order and connections; the other considers the mathematical formula as "the point through which all the light gained by science must pass in order to be of use in practise."

It is clear that observation alone is insufficient for the understanding of a physical fact. Liebig has formulated three conditions which he considers necessary:

We must first study and know the phenomenon itself, from all sides; we must then determine in what relation it stands to other natural phenomena; and lastly, when we have ascertained all these relations, we have to solve the problem of measuring these relations and the laws of mutual dependence—that is, of expressing them in numbers.

On this view we should have, apart from measurement and hence apart from mathematics, no science except in the preliminary stage preceding the considerable development of any chapter. Some have gone further and have maintained that there is no science whatever except that which stands definitely and clearly on measurement, that the essence of science in the whole and in every part is measurement and solely this.

But this extreme view is not upheld by the position of modern science. There is a significant chapter of chemistry, for instance, in which precise results of a definite character are obtained under the guidance of a theory in which something essentially different from measurement holds the central place, namely, the linking and spatial arrangement of atoms in the molecule. There is a difference of properties accompanying identity of molecular formulæ where we are forced to admit even the same atomic linking and can ascribe the existing difference only to unlike positions of atoms in the molecule. This

is the central notion in the chapter. It has been formulated so definitely and the facts of experiment have been associated with it so closely that there can be no doubt of its correspondence with some essential reality as the main feature involved. It is obviously not in the same class of ideas with measurement.

This leaves unanswered still the question as to whether a self-contained body of well-developed scientific truth can be isolated which has been established and may be expounded without essential use of the method of measurement. It will readily be admitted that some of the preliminary work in the creation of a science consists in the description of phenomena and their analysis as to qualitative aspects. But it seems that we can not bring any chapter of science to a resting state of relative completeness until we have laid the basis for it deep on a foundation of accurate measurement. In the example cited from stereochemistry, for instance, we have in the advanced stages a portion of theory depending primarily on considerations of relative positions in space; but antecedent to the development of this portion of the theory and necessary to its creation and even to an understanding of it is a large body of doctrine resting on detailed measurement.

It appears, therefore, that no science can come to a relatively high state of development until it has been made to rest on a mathematical foundation. Those who insist most strongly on the kinetic or mechanical view of nature appear to believe that physics and chemistry, the basic sciences of natural phenomena, "are destined to become ultimately merely chapters in dynamics as the doctrine of mechanical motion." But probably Maxwell is nearer the heart of the matter when he insists that a physical theory should be at the same time both mathematical and physical.

It seems that no body of thought has at the same time been of more importance in human progress and been criticized more freely than the science of mathematics. Much of this criticism appears to be good-natured and to amount to but little more than a quasi-humorous way of expressing the critic's own unashamed ignorance. At first sight one might treat this as harmless; but from the point of view of the general interest it can hardly be passed over in such a way. How this ignorance is to be overcome I can not say. Perhaps one of the first requisites is to find some means of overcoming the shamelessness with which individuals otherwise well trained contemplate their own ignorance of mathematics.

The mathematician himself is not disturbed so far as the welfare of his own science is concerned; but it is sometimes a

matter of pain to see the general loss which arises from such ignorance and also from the severer strictures of the more pronounced adversaries of mathematics. In no other case, however, have the criticisms been so severe as those meted out to the infinitesimal calculus in the infancy of its development; and never have the fondest hopes of the founders of a science been so far surpassed by its actual achievements as here where the subject has become central in practically every field of pure and applied mathematics.

It will be instructive to examine briefly the criticisms thus met so early by the infinitesimal calculus. Some persons attacked the certainty of its principles, attempting to show that its conclusions were at variance with those obtained by methods previously known and accepted as sound. Some who labored primarily with matters of morality and religion attacked the new departure of thought on general grounds; they repulsed themselves by unwittingly displaying their ignorance of the thing which they criticized. One man, who entrenched himself in masses of calculation, pronounced the procedure of the new calculus unsatisfactory because of the indeterminacy of the form in which certain results appeared; but he afterwards acknowledged his error and admitted that he had been urged forward by malevolent persons—a thing (let us believe) which does not often happen among workers in science. Christiaan Huygens, whose opinion probably carried more weight than that of any other scientific man in his day, believed that the employment of differentials was unnecessary and declared that Leibnitz's second differential was meaningless. But these and many other criticisms never hindered the development of the new calculus, but served rather to aid in clearing off certain excrescences which had nothing to do with its essential characteristics and in helping it to that central place of importance which it holds to-day.

The criticism last mentioned is one which is made so often that it is profitable to dwell longer upon it. So often the mathematician hears: "What is the use of what you are doing?" He knows a thousand answers to this question; and one of the most effective is that which history has given to the criticism of the illustrious Huygens. The recently developed subject of integral equations has sometimes been confronted with the inquiry: Why develop this theory? Will not differential equations serve the purpose? But the mathematician goes calmly ahead with the development of those things which interest him, just as he did formerly; and in the new case he anticipates with confi-

dence the same triumphant justification in the event which has uniformly crowned his labors in the past.

The natural sciences have also been subjected to the same criticism. A narrow view of practical usefulness seems always to dim the vision of those who are unlearned in the progress of scientific discovery and the means which have released into activity the powers of man. They judge from the standards of a daily life in which the prime energy is constantly given to procuring food and shelter or to laying up a store for the future; and it is hard to see the values in a work which does not contribute directly and immediately to such ends. They are not to be judged harshly for this error. It must be admitted that the experience of most of their ancestors leads in the direction of this false judgment on their part. A small number only of the men of each generation see clearly the remoter concerns of mankind; and even they have come to this vision partly from the spur of astonishment at the wonderful values evolving from time to time from abstract considerations.

One of the most remarkable and immediate of these unpredicted values, and at the same time one of the more modern, is afforded by the germ theory of disease. In the middle of the nineteenth century bacteria were known only to a few experts and in a few forms as curiosities sometimes appearing in the field of vision under the microscope; and no one dreamed of their being of importance to man. In fact those who studied them were thought to be wasting useful energy and were subjected to ridicule. But in the midst of wild conjectures and worse logic a nucleus of facts was isolated and some understanding of them began to be realized. In 1860 putrefaction in wounds was ascribed to them, and a few years later their relation to certain diseases began to be known. Then a knowledge of their life-history and action developed rapidly. To-day we understand not only how they are of great concern to us in disease, but also how their action in other ways is of profound importance to our welfare. They are so essential to agriculture, for instance, that our race could not long preserve itself in the present numbers and state upon the earth if the soil were not constantly renewed through the activity of certain of these minute organisms.

Throughout its whole range, from the most abstract considerations in mathematics to the concrete descriptive developments of bacteriology, science at some stage must face the insistent question of its usefulness; and this question it is always answering in ways astonishing even to its ardent supporters.

In the development of physics the infinitesimal calculus has

persistently played a leading rôle; its interaction with experimental results has been and is fundamental and necessary to the progress we have witnessed and yet see to-day. From this creation of the mathematicians and the use made of it by the physicists the world has received a good practically immeasurable in its extent. Sometimes we are tempted to assess the advantages due to each of these elements; but one can hardly expect success from such a venture. Logically the mathematics is prior; for it could exist of itself, while the physics probably could not. But psychologically and practically they are so bound up that no separation can be made. Were the mathematics swept away, much of physical theory would likewise have to go; but on the other hand much of the mathematics would never have existed had it not been called into being by the demands of physical science.

This affords us a beautiful and instructive figure of the interaction of one body of truth with another. Neither of these two would exist in their modern state without the spur which it has received from the other. Neither of them should glow with a spirit of boasting. A humble acknowledgment of fundamental indebtedness is more fitting; and it is pleasant to see each characterized by a fervent zeal to return good for good in full measure.

Before turning aside from the relations between natural science and mathematics let us consider briefly a conception or expectation which has arisen in some quarters and having to do with a more fundamental and far-reaching use of mathematics than any yet made. It is connected with the fact that every branch of physics gives rise to an application of mathematics and the consequent feeling that there must be a deep underlying reason for this and a subsequent close relation of phenomena which probably makes them capable of an explanation from a single point of view consistently maintained.

If there is a "hypothetical substructure of the universe, uniform under all the diverse phenomena," it would appear that there must be some means of ascertaining what it is and of giving to it a mathematical expression and body. At any rate the expectation of such a thing has arisen; let us hope that the event will show that the anticipation is well grounded in the nature of things.

It appears that the earliest contributions to just such a development are already in existence; that the now current theoretical accounts of radiation, diffusion, capillary action and molecular behavior in general have just such characteristics as one would expect to find in the early stages of a mathematical theory of the substructure of the universe.

At the opposite pole of knowledge is another stream of thought whose existence or influence is mainly left out of account by scientists just because it is so far removed from that with which they are accustomed to work. But it has profound influence upon life and even affects science in some measure directly though remotely. This is the unsystematic thought which finds expression in literature and art and sometimes in unorganized philosophic speculation. For the most part the domains of systematic and unsystematic thought have little effect the one upon the other; and yet it must be apparent to one who analyzes the fundamental characteristics of our age that these two great arteries of our culture must have somewhere a vital connection. Only rarely does an important truth find its first expression in unsystematic thought and later take up a place in science; and when it does so it is much changed in the process. The poetry of science has not been written and its cultural elements have not found their way into the general thought of mankind.

And yet all science must receive its initial spring from ideas no more definitely organized than the vague intuitions which strive only half successfully for expression in the form of literature or art. Between the two there is, however, this fundamental difference. Even in its early stages a branch of science has to do only with a restricted range of phenomena. It is necessary to study small sets of closely related matters if we are to get that detailed information on which alone science can rest. We can not obtain definite and precise scientific information about the whole environment at once. We must take it by piecemeal; and so far we have succeeded only where we have isolated the phenomena into distinct and sharply-defined groups. It is quite otherwise in literature, for instance. Here the whole stream of life is contemplated at once, in its fullness and complexity. The results obtained are less definite and are more subject to change from age to age than those of science. Moreover there is less uniformity in the way in which they affect the individuals who consider them. But they have a breadth of reach over the forces of life and the motives of conduct which can be realized only by a single grasp of the whole complex process. Each of these two realms of thought, in its central characteristics, has lessons of value for the other.

Between these two extremes is a middle ground lying undeveloped. One can hardly feel that it is covered by the generalizations of philosophy. To synthesize the results from the separated domains is hardly enough. One desires a means of grasping a more complex portion of reality, vibrant with the

pulse of life, and of reducing it to definite order. It appears that no known methods are sufficient for dealing with this problem. Shall we conclude that it is impossible of solution or merely that we have need of a further development before we can expect success with it? Thought as embodied in literature and art took a wonderful form in ancient Greece. There science had merely a beginning and did not acquire sufficient strength to live vigorously through the middle ages. Many centuries were still necessary for a development of its method. Will another period of like extent lead us to other methods equally novel and suitable for the development of this middle territory between literature and our present science?

The logical evolution of science from the vague to the definite is instructive from many points of view. Through untold periods of time for many ages the human mind moved very slowly toward that isolation of phenomena in thought which is essential to the creation of exact science. In action such isolation can not be effected; we must take the whole complex environment at once and do the best we can. This characteristic of the practical life has doubtless been one of the chief factors in delaying the abstractions now so uniformly present in scientific investigation.

In the construction of each particular science we pass through a sequence of stages similar to those which have characterized our general progress in the development of science as a whole. First of all, there is a period in which a given class of phenomena affect us vaguely and we are only half-conscious of their presence as a connected entity in the complex of the environment. They continue to affect us and we have a growing sense of related experiences proceeding from a common source. This arrests attention and excites interest. From being merely passive recipients of impressions we now come to be active in our relation to the phenomena; we observe them directly, and we seek means to affect them so as to ascertain their course or character with more accuracy. We pass to the stage of vague and gross qualitative description of the phenomena. In the course of our study this gives way to a qualitative analysis of the phenomena and a study of their qualitative relations of co-existence. Such is the state to which the biological sciences of the present day have attained. Sociology finds its place even further back in the scale.

Qualitative considerations never become definite enough to meet the ideals of science. It is necessary to go further and find out the quantitative aspects of phenomena and to determine the exact relations of their coexistence and succession; in

a word, to render the account mathematical. Once Newton and his followers had succeeded in deducing from a few laws, easily stated and comprehended, the essential facts of astronomical motion as obtained by direct observation, it was impossible that any science should rest comfortably in a state in which qualitative considerations are dominant. The astronomical view was certain to spread into molar and molecular physics and even to find a place in the biological sciences.

The various divisions of physics proper were the first portions of other sciences to approach the ideal conceived on account of the success in astronomy; and chemistry has followed at a distance. As late as 1873 it could be said:

No theory has as yet been formed in chemistry which, starting from a definite principle, attempts to deduce results of experience as necessary consequences.

Measured by the standards attained by Maxwell and his followers in the theory of electricity, chemistry is still seen to be far short of that standard of excellence which we are able to conceive definitely, notwithstanding the remarkable developments which a generation has witnessed. Perhaps it will not find its true place until we are in possession of more effective means for getting into the atom—not merely the molecule—and studying the properties and connections and positions of its parts.

When a science has reached a certain stage of development, varying greatly with the character of its material, it begins to throw off into the body of society great practical or even esthetic values which could not be realized without it. Astronomy has enabled us to have some conception of the vastness of space and the hugeness of the mass of matter, perhaps infinite in its totality, distributed through this space. Geology has released the imagination to contemplate the enormous periods of time and through its influence on biology has rendered marked service in making possible our conception of the long progress of life on the planet, culminating in man. Mathematics, by exhibiting a body of truth which can live through millenniums without needed corrections and at the same time can grow in magnitude and range and interest, has given the human spirit new ground for believing in itself and for rejoicing in its proved power of consistent thought.

In addition to values of this more ideal sort there are others of a practical nature. Two of the most remarkable are those afforded by chemistry and the theory of electricity. The latter has enabled us to transmit readily and over great distances immense stores of energy, either from a central plant or from

some permanent source in nature, and to utilize it for a great variety of purposes. The former has furnished the necessary means for founding certain industries and has contributed essential elements to the maintenance of many others.

But the excellence of science is not altogether in itself or in its fruits. It has interactions with all the fundamentals of life and thought. It moves upon itself, part upon part, and so brings out many values. Of especial import is the effect within itself of the influence exerted by mathematics and natural science, the one upon the other. But it reaches out also beyond its own domain into all the activities of man, both practical and theoretical and speculative. It so moves in his philosophy that thinkers not a few now maintain that the present duty and function of philosophy is to think science, to organize its results and to scrutinize their validity. It so affects daily life in many ways that it can not fail to exert a profound influence upon the unsystematic thought of literature and art as they strive to give expression to the fundamental spirit of life in our age.

From a certain point of view these four main divisions of Thought—mathematics, natural science, philosophy, that unnamed one ruling without definite system in the domain of art and literature—are the stones and brick and mortar from which is builded the culture of the time, into which are wrought the values received from the past, and through which our development shall proceed to the acquisition of new power for further conquest. We break the environment into parts in thought and from these we fashion new objects such as never before existed in the universe—objects both concrete and ideal—and these we put together in ways well-pleasing to ourselves to serve the ends we propose or erect the constructs we conceive.

But this is too mechanical to be the whole truth. The more profound values lie deeper and have their fruition only in the fullness of the character of man. If science did not touch a more profound matter than mere motion or reach to constructs which can not be adequately pictured by material symbols, it would fall far short of the glory of Living Thought. But it does react in a profound way with all our activities. In fact, the elements of all Thought are parts of one body, living and organized, inspired by the breath of the Universe itself and pulsating with the life of truth in its deeper manifestations.